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"A Study of Supply Chain Management System Using Optimization Techniques"

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Submitted by

MS. SINDHU RAMRAO DHAVALE

Research Scholar

(PRN NO. 202150107002)

Under the Guidance of

DR. GAJANAN CHANDRAKANT LOMTE

Associate Professor

Department of Mathematics

CSMSS, Chhatrapati Shahu College of Engineering

Chhatrapati Sambhajinagar (MS), India.

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1.Introduction:

The concept of a Supply Chain Management is primarily concerned with the efficient integration of suppliers, factories, warehouses and stores so that merchandise is produced and distributed in the right quantities, to the right locations and at the right time, and so as to minimize total system cost subject to satisfying customer service requirements. Supply chain management has been defined as the "design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally. supply chain encompasses a series of processes involving multiple entities such as suppliers, manufacturers, distributors, and retailers. These entities collaboratively work to procure raw materials, transform these materials into products, and distribute these products to consumers. The nature of a supply chain is profoundly integrative, focusing on both the forward flow of materials and backward flow of information. The study introduces the dynamics of supply chains and discusses their critical components including procurement, production planning, distribution and logistics underlining the importance of efficient management to enhance overall performance. A supply chain is basically a group of independent organizations connected together through the products and services that they separately and/or jointly add value on in order to deliver them to the end consumer. It is very much an extended concept of an organization which adds value to its products or services and delivers them to its customers. A supply chain is a network that connects a company to suppliers of raw materials. It is also used to deliver a product to customers. The better the supply chain management, the more of a competitive advantage the company has.

Supply chains are steps that are required to get raw materials, products or services from the original state to the customer and improve customer relations. Large companies and projects usually have more than one supply chain, which is known as a supply network. Having supply chain managers and supply chain management is key to delivering customer value and maximizing the efficiency of your supply network.

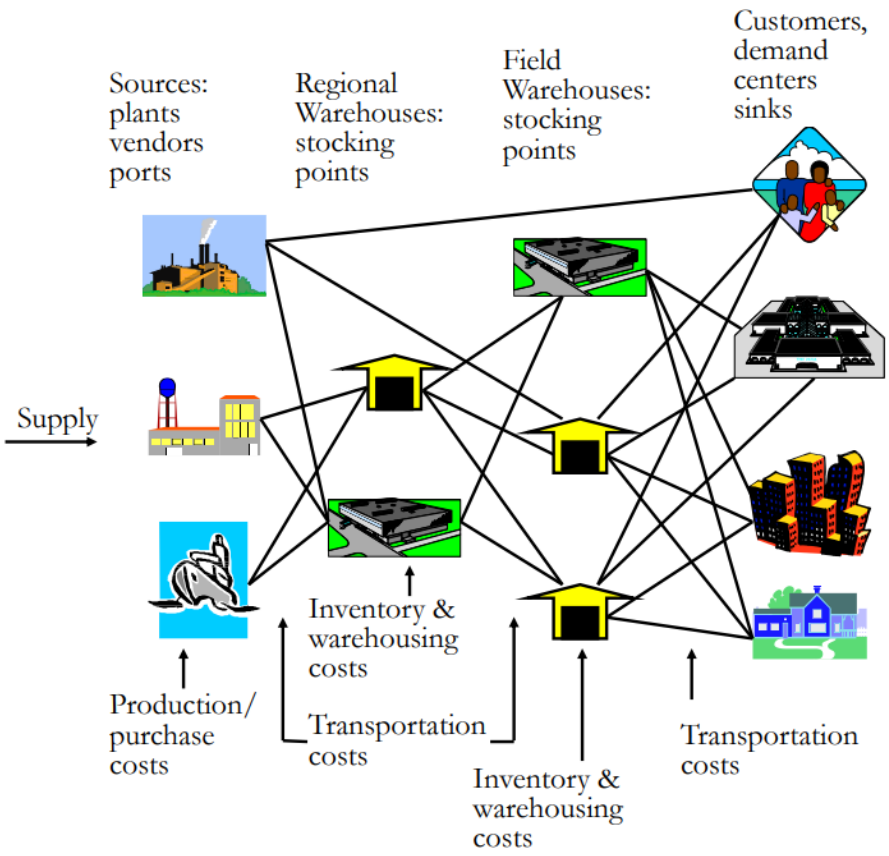

Fig.1.1 Supply Chain network

1.1 Optimization in Supply Chain Management

Today's global marketplaces are not just battles between companies but between entire supply chains. supply chain management (SCM) has emerged as a critical area for achieving competitive advantage and operational excellence. Central to the effectiveness of SCM is the application of optimization techniques, which are mathematical and computational strategies designed to enhance decision-making processes. These techniques are vital for navigating the complexities of modern supply chains, which encompass a vast network of suppliers, manufacturers, distributors, and retailers, all interconnected and dependent on efficient coordination.

Optimization techniques in SCM are utilized to address a wide array of challenges, including the efficient allocation of resources, minimization of costs, maximization of service levels, and management of risks and uncertainties. By applying these techniques, organizations can

streamline operations, reduce waste, and improve the overall performance of the supply chain. This, in turn, leads to significant benefits such as cost savings, improved customer satisfaction, and enhanced sustainability.

Optimization techniques play a vital role in supply chain management (SCM) by enhancing efficiency, reducing costs, and improving customer satisfaction. These techniques enable the efficient use of resources such as raw materials, labour and capital, minimizing waste and redundancies to achieve higher productivity. They streamline processes across procurement, production, and distribution, resulting in faster and more reliable operations. By optimizing routes, inventory levels, and production schedules, companies can significantly lower operational costs, including those related to transportation, warehousing, and manufacturing.

In addition to cost reduction, optimization techniques are crucial for better decision-making. They allow companies to evaluate multiple scenarios and choose the most cost-effective solutions. Enhanced service levels and accurate demand fulfilment are direct benefits, as optimization ensures timely delivery of products in the right quantities, thereby boosting customer satisfaction.

Optimization techniques also contribute to sustainability by reducing the environmental impact of supply chain activities. They minimize energy consumption, lower emissions, and optimize waste management, promoting sustainable practices through efficient resource use and reduced carbon footprints.

Strategically, optimization aids in long-term planning, offering insights into network design, facility location, and capacity planning. Companies leveraging these techniques gain a competitive edge by operating more efficiently and responsively. Effective inventory management is another advantage, as optimization maintains optimal inventory levels, reducing both overstock and stock outs and supporting just-in-time (JIT) systems.

Finally, optimization techniques are integral to integrating advanced technologies like artificial intelligence, machine learning, and big data analytics in SCM. They enable automation of complex decision-making processes, reducing reliance on manual interventions and minimizing human error. Overall, optimization is indispensable in modern supply chain management, driving improvements in efficiency, cost savings, customer satisfaction, risk management, sustainability, and performance.

2. Review of Literature:

Simchi-Levi et al. [1] discuss the application of network optimization models for facility location, distribution network design, and transportation routing to minimize overall costs and improve operational performance. Linear programming has been extensively utilized in supply chain management for optimizing various operations, including production planning, inventory management, and transportation logistics. Martina Grubisic et al. [2] explore linear programming for land allocation in vegetable production, extending their analysis to dynamical optimization and crop rotation rules. Although their method proved effective for specific local contexts, it lacked the scalability and adaptability required for larger, more complex global supply chains. Mariana E. Cóccola et al. [3] present an integrated approach to optimizing resource flows in the dairy industry. While these methods enhanced efficiency, they fell short in addressing critical perishability and variability factors that are intrinsic to the food industry. Babagolzadeh et al. [4] present a multi-objective fuzzy programming model aimed at designing a sustainable supply chain network, considering disruptions. This model integrates sustainability with the robustness of supply chains, ensuring resilience against potential disruptions. Bas and Ozkok [5] introduce a fuzzy approach to a multi-objective mixed-integer linear programming model for a multi-echelon closed-loop supply chain with multiple products and time periods. This research emphasizes the integration of closed-loop systems and the handling of multiple time periods, adding depth to the optimization techniques in supply chain management. Alavidoost et al. [6] propose a novel fuzzy mathematical model for integrated supply chain planning using a multi-objective evolutionary algorithm. Their work enhances the understanding of evolutionary algorithms in optimizing complex supply chain networks. Raj et al. [7] focused on minimizing transportation costs in the dairy industry by optimizing vehicle routes for a public sector milk dairy in Madurai. Acknowledging that risk and uncertainty are inherent in supply chains, especially for perishable goods requiring specific transportation and storage conditions, they aimed to enhance efficiency by shortening routing distances. Feili and Khoshdooni [8] developed a fuzzy optimization model for tactical planning in multi-echelon, multi-product supply chains, offering flexible decision plans under uncertainty. Kittipong Luangpantao et al. [9] emphasize the importance of effective supplier selection processes, utilizing fuzzy set theory to handle uncertainties. M. Moayeri et al [10]. used Fuzzy AHP and Fuzzy Topsis methods for the selection process of math teachers. Rajendra Kumar Sukla et al. [11] proposed an integrated approach of Fuzzy AHP and Fuzzy Topsis in modeling supply chain management systems. Kousar et al. [12] propose a multi-objective intuitionistic fuzzy

linear programming model for optimizing industrial closed-loop supply chain networks. Their study focuses on closed-loop supply chains, contributing to the sustainable management of industrial networks. Mardanya et al. [13] address bi-level multi-objective transportation problems under fuzziness. This study provides insights into handling transportation issues at multiple levels of decision-making, which is critical for comprehensive supply chain management. Shafiee et al. [14] present a robust multi-objective optimization model for inventory and production management with environmental and social considerations. Their case study in the dairy industry demonstrates the practical applicability of their model in real-world scenarios, emphasizing sustainability and social responsibility. Singh and Goh [15] develop a multi-objective mixed-integer programming model for a pharmaceutical supply chain, addressing the need for balancing multiple objectives in complex supply networks. Their research provides a detailed analysis of how mixed-integer programming can be utilized to optimize supply chain performance in the pharmaceutical sector. Bhatia and Bhat [16] explore the operational aspects of agricultural supply chain management, offering an in-depth perspective on managing supply chains in the agriculture industry. Their study underscores the importance of operational efficiency and strategic planning in agricultural supply chains. Taylor and Murphy [17] investigate sustainability practices and optimization in supply chains, proposing a model for green logistics. Their work is significant in the context of increasing environmental concerns, offering strategies for integrating sustainability into supply chain management.

3. Nature and Scope

Today's global marketplaces are not just battles between companies but between entire supply chains. This study asserts that SCM is not only pivotal for achieving corporate success but also for enhancing customer satisfaction and societal well-being. The role of e-business and electronic commerce in SCM, especially under the framework of just-in-time distribution strategies, underscores the evolving nature of consumer-business interactions and the continuous need for adaptive strategies.

The world itself is a one big supply chain. In the present day competition is no longer seen as the company against the company but the supply chain against the supply chain. Supply chain management is therefore a new perspective towards the old activities. Supply chain management touches major issues, including the rapid growth of multinational corporations and strategic partnerships; dramatically affects corporate strategy and bottom line.

Supply chain management can be applied to customer satisfaction and company success, as well as within societal settings and it can help improve quality of life. Supplier selection, the process of determining the suitable suppliers who are able to provide the buyer with the right quality products and/or services at the right price, at the right time and in the right quantities, is one of the most critical activities for establishing an effective supply chain.

So keeping in point of view, the following objectives were taken for the present study in supply chain management.

4. Objectives of the Research Study:

The objectives of the research work entitled " **A Study of Supply Chain Management System Using Optimization Techniques** " include:

1. To study existing optimization models in supply chain management.
2. To developed a linear programming model for optimization of multistage multi modal supply chain management.
3. To developed fuzzy linear programming model for optimization of multistage supply chain network using alpha -cut approach.
4. To use Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods in fuzzy environment for supplier selection.
5. To propose a Transportation Model for minimizing cost at various stages of supply chain.

5.Research Methodology:

The systematic methodology developed for an Operation Research(OR) study deals with problems involving conflicting multiple objectives, policies and alternatives. OR is a scientific methodology which is useful to the study of the operations of large complex organizations or activities with a view to assessing the overall implications of various alternative courses of action. The following are some steps consist to solve the problems using OR approach:

- Formulate the problem
- Construct a mathematical model
- Acquire the input data
- Derive the solution from the model

- Validate the model
- Establish control over the solution
- Implement the final results

The Optimization techniques employed in this research work are as follows:

5.1 Linear Programming Problem (LPP)

Linear programming (LP) also called linear optimization is a technique for determining an optimum schedule of interdependent activities (such as maximum profit or lowest cost) in view of the available resources. The word 'planning' is referred as programming and use the method of finding a particular plan of action from available several alternatives The word linear means that, all relationships involved in a particular problem are linear. LP is a special case of mathematical programming (mathematical optimization)

5.1.1 Transportation Problem(TP):

The TP is a special type of LPP where the objective is to minimize the cost of distributing a product from a number of sources or origins to a number of destinations. Because of its special structure the usual simplex method is not suitable for solving TP's. These problems require a special method of solution. The origin of a TP is the location from which shipments are dispatched. The destination of a TP is the location to which shipments are transported. The unit transportation cost is the price of shipping one unit of the consignment from an origin or source to a destination.

A TP when expressed in terms of an LP model can also be solved by the simplex method. However, a TP involves a large number of variables and constraints', solving it using simplex methods takes a long time. That's why, transportation algorithm namely Stepping stone method and modified distribution method (MODI) have been developed for solving a TP.

The classical TP can be described in a special case of LPP and its models are applied to determine an optimal solution of the TP required for deterministic of how many units of goods to be transported from each origin or source to various destinations where the objectives have to optimize (minimize or maximize) price or time. There various types of transportation models and simplest of them was first presented by F.L. Hitchcock in 1941. TP further developed by T. C. Koopmans in 1949 and G.B. Dantzing in 1951.

- **General Mathematical Model of TP**

Let there be m sources of supply, S1, S2……Sm having a_i (i=1, 2…., m) units of supply (capacity), respectively to be transported to n destinations, D1, D2,…….. ,Dn with bj (j=1,2,…….) units of demand (or requirement), respectively. Let c_{ij} be the price of shipping

one unit of the goods from source i to destination j. If x_{ij} represents number of units transported from i to destination j, the problem is to establish the transportation schedule so as to minimize the transportation cost while satisfying the supply and demand conditions. Mathematically, the TP, in general can be written as

$$\text{Minimize (total cost) } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}\, x_{ij} \quad (1)$$

Subject to constraints

$$\sum_{j=1}^{n} x_{ij} = a_i, \quad i = 1,2, \ldots \ldots m \text{ (Supply constraints)} \quad (2)$$

$$\sum_{i=1}^{m} x_{ij} = b_j, \quad j = 1,2, \ldots \ldots n \text{ (Demand constraints)} \quad (3)$$

$$x_{ij} \geq 0 \text{ for all } i \text{ and } j.$$

- **Terminologies in Transportation Problem (TP)**

The terminologies used in the thesis are described here.

- **Objective function:**

The linear function

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}\, x_{ij}$$

Which is to be minimized or maximized is called the objective function of the general TP.

- **Constraints:**

There are always certain limitations (constraints) on the use of resources, labour, raw material, money etc. that limit the degree to which a goal can be reached. Such constraint must be expressed as linear inequalities or equalities in terms of decision variables. The equations (2) and (3) are the constraints of the general LPP.

- **Optimum Solution:**

Any feasible solution which optimizes (minimizes or maximizes) the objective function of a general LPP is called an optimum solution to the general solution.

- **General Algorithm of TP**

Step I : Formulate the problem and arrange the data in matrix form. The Formulation of the TP is similar to LPP formulation.

Step II : Check whether total supply equals total demand. If not introduce a dummy row Or column having all its cost elements as zero and Supply or Demand as the Positive difference of Supply and Demand.

Step III : Find an initial basic feasible solution (IBFS) that must satisfy all the Supply and

demand conditions.

Step IV : Examine the solution obtained in step III for optimality, i.e. whether better Transportation schedule with lower price is possible.

Step V : If the solution is not optimum, modify the shipping schedule by including that Unoccupied cell whose inclusion may result in an improved solution.

Step VI : Repeat step V until no further improvement is possible.

There are number of methods to obtain an IBFS. However, the following are Mostly used:

- North-West Corner Method
- Least-Cost Method and
- Vogel's approximation method (VAM) (or Penalty method)

➢ **Test for Optimality**

Generally, there are two methods used to find out optimal solution. i.e. 1) Modified Distribution Method (MODI) or (u - v) Method. 2) Stepping Stone Method.

5.1.2. Integer Linear Programming Problem (ILPP)

A LP having all or some of the decision variables are constrained to assume non-negative integer values is called an integer programming problem (IPP). The integer solution to a problem can be obtained by rounding off the optimum values of the nearest integer values.

The LPP with the additional requirements that the variables can take only, integer values may have the following form

Optimize (Min or Max) Z = c_1x_1+c_2x_2+……+c_nx_n

Subject to the linear constraints,

$$a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n(\leq, =, \geq)b_i$$

$$i = 1,2, \dots, m$$

$$j = 1,2, \dots, n$$

And $x_j \geq 0$

Where x_j are integer valued for $j = 1,2, \dots, p(p \leq n)$.

There are three categories of IPP, as

An IPP in which all variables are required to be integers is called a pure or all-IPP.

Whereas, an ILPP in which some of the variables are required to be integers, is called as mixed integer linear programming problem (MILP).

5.1 Fuzzy Set Theory:

Zadeh (1971) propose that as the complexity of a system increases, our ability to make precise and yet significant statements about its behaviour diminishes until a threshold is reached. Beyond this threshold, precision and significance become almost mutually exclusive characteristics. This implies that precise quantitative analyses of the behaviour of humanistic systems are unlikely to have much relevance to real-world societal, political, economic, and other problems involving humans either as individuals or in groups.

Terms used in fuzzy set theory:

5.2.1 Membership Function

Let X be a classical set of objects whose elements are denoted by x. Membership in a classical subset A of x is often viewed as a characteristic function $\mu_A(X)$ from X to a valuation set $\{0,1\}$ such that

$$\mu_A(X) = \begin{cases} 1, & iff\ x\ \mathcal{E}\ A \\ 0, & otherwise \end{cases}$$

A fuzzy set is a set containing elements that have varying degrees of membership in the set. The valuation set is allowed to be real interval [0, 1]. Fuzzy set A of the universe X is characterized by a membership function μ_A, which takes its value in interval [0, 1]. The closer the value $\mu_A(X)$ is to 1, the more x belongs to A.

5.2.2 α-cut set:

The α-cut set A_α is made of members whose membership is not less than α.

$$A_\alpha = \{x\ \mathcal{E}\ X \mid \mu_A(x) \geq \alpha\}$$

where $\mu_A(x)$ is the membership function of x in A and α is an arbitrary threshold value.

5.2.3 Convex Fuzzy Set:

Assuming universal set X is defined in n-dimensional Euclidean Vector space $\Re^n$. If a relation

$\mu_A(t) \geq \text{Min}[\mu_A(r), \mu_A(s)]$

where $t = \lambda r + (1-\lambda) s$; $r, s \in \Re^n, \lambda \in [0,1]$

Holds, the fuzzy set A is convex.

5.2.4 Fuzzy number

If a fuzzy set is convex and normalized, and its membership function is defined in R and piecewise continuous, it is called as fuzzy number

5.2.5 Triangular fuzzy number:

A TFN $\tilde{A}$ is specified by the triplet (a_1, a_2, a_3) and is defined by its continuous membership function $\mu_{\tilde{A}}(x):X \to [0,1]$ as follows:

Membership function of TFN

$$\mu_{\tilde{A}}(X) = \begin{cases} \frac{x-a_1}{a_2-a_1}, & if\ a_1 \le x \le a_2 \\ \frac{a_3-x}{a_3-a_2}, & if\ a_2 \le x \le a_3 \\ 0 & otherwise \end{cases}$$

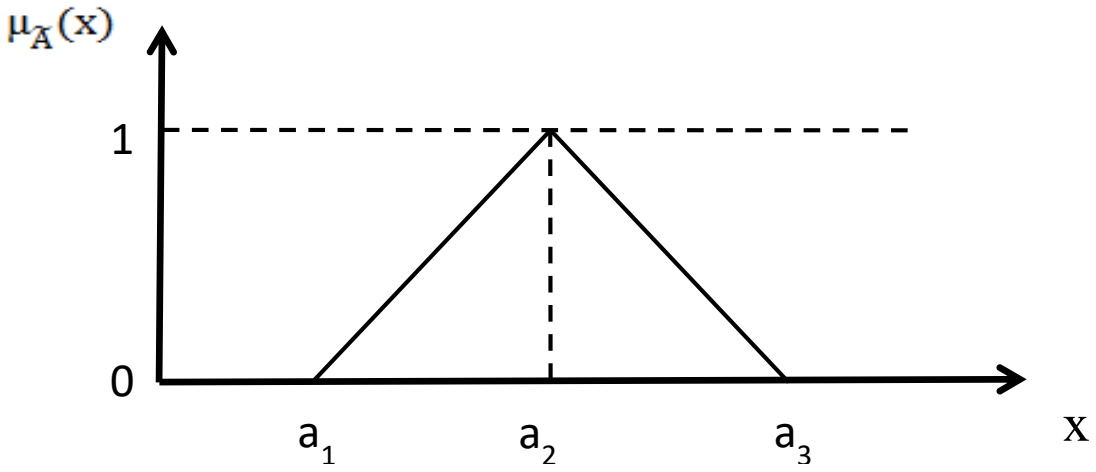

Fig 1.2: Membership function of triangular fuzzy number

5.2.6 Trapezoidal membership function:

A trapezoidal fuzzy number $\tilde{A}$ is specified by four parameters (a_1, a_2, a_3) and is defined by its continuous membership function $\mu_{\tilde{A}}(x):X \to [0,1]$ as follows:

- **Membership function of Trapezoidal fuzzy number**

$$\mu_{\tilde{A}}(X)=\begin{cases}\frac{X-a_1}{a_2-a_1} & if\ a_1 \le X \le a_2 \\ 1 & if\ a_2 \le X \le a_3 \\ \frac{a_4-X}{a_4-a_3} & if\ a_3 \le X \le a_4 \\ 0 & otherwise\end{cases}$$

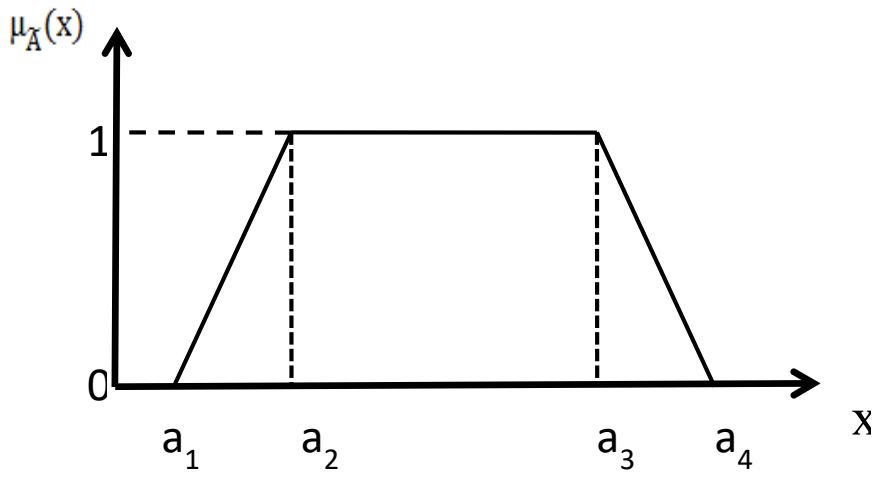

Fig 1.3: Membership function of trapezoidal fuzzy number

5.3 Fuzzy Analytic Hierarchy Process (FAHP):

Thomas L. Saaty initially proposed the analytic hierarchy process (AHP), which has become a widely used multiple criteria decision-making tool. Since its invention, AHP has been extensively utilized by decision-makers and researchers, making it one of the most prevalent tools in multiple criteria decision-making. However, the traditional AHP method has certain limitations, particularly in using exact values to represent the decision maker's opinions when comparing alternatives. This approach is often criticized for its unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pairwise comparison process.

To address these shortcomings, the fuzzy analytic hierarchy process (FAHP) was developed. FAHP enhances the traditional method by incorporating fuzzy logic, allowing for a more nuanced and flexible expression of the decision maker's preferences, thus effectively addressing the inherent uncertainty and imprecision in hierarchical decision-making problems.

By using fuzzy numbers and linguistic variables, FAHP can model the subjective judgments of decision-makers more accurately, providing a more realistic and robust framework for decision-making.

FAHP has been widely applied in various fields, including supply chain management, project evaluation, environmental management, and resource allocation. Its ability to handle vague and ambiguous information makes it particularly useful in complex decision-making environments where traditional AHP may fall short. The integration of fuzzy set theory with AHP allows for the creation of more reliable and valid decision models, enhancing the decision-making process in both qualitative and quantitative aspects. This makes FAHP a powerful tool for tackling multi-criteria decision-making problems in real-world scenarios, where uncertainty and imprecision are often unavoidable.

5.4 Fuzzy TOPSIS Method:

The TOPSIS method was first proposed by Hwang and Yoon. The core concept of this method is that the selected alternative should have the shortest distance to the positive ideal solution and the longest distance from the negative ideal solution. The positive ideal solution maximizes benefit criteria and minimizes cost criteria, while the negative ideal solution maximizes cost criteria and minimizes benefit criteria. In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely, and crisp values are used in the evaluation process. However, crisp data often fall short in modelling real-life decision problems. To address this inadequacy, the fuzzy TOPSIS method was developed, where the weights of criteria and ratings of alternatives are evaluated using linguistic variables represented by fuzzy numbers, thereby addressing the deficiencies of the traditional TOPSIS.

The fuzzy TOPSIS method improves the decision-making process by incorporating the inherent uncertainty and imprecision associated with human judgments. By using fuzzy numbers, it allows for a more flexible and realistic representation of the decision-maker's preferences and assessments. This method is particularly useful in complex decision-making environments where precise data is unavailable or difficult to obtain. The fuzzy TOPSIS method has been successfully applied in various fields, including supply chain management, environmental assessment, and project selection, demonstrating its versatility and effectiveness in handling multi-criteria decision-making problems under uncertainty.

Furthermore, the fuzzy TOPSIS method enhances robustness and reliability in decision-making by accommodating the vagueness and ambiguity that are often present in real-world scenarios. It provides a systematic approach to aggregate and analyse subjective judgments, enabling a

more comprehensive evaluation of alternatives. The method's flexibility in handling different types of data and criteria makes it a valuable tool for decision-makers seeking to achieve optimal solutions in uncertain and dynamic environments. As a result, the fuzzy TOPSIS method has become an essential technique in the toolkit of researchers and practitioners aiming to address the complexities of modern decision-making processes.

6. Contribution Made to the Existing Knowledge:

Our research enhances existing knowledge in Supply Chain Management (SCM) by introducing a deterministic mathematical model that integrates opportunity costs, ensuring timely material availability and product transportation and efficient operation across suppliers, manufacturers, and warehouses. To address uncertainties in cost and demand, we propose a fuzzy mathematical programming model using the α-cut approach, capturing real-life flexibility. We also employ Fuzzy AHP, Fuzzy SWARA, Fuzzy TOPSIS, and Fuzzy TOPSIS with Fuzzy AHP methods, providing robust decision-making frameworks under uncertainty. An illustrative example demonstrates the application of these methods. The proposed models are versatile, offering optimal solutions for both small-scale and large-scale industries, thereby significantly contributing to the field's existing knowledge.

7. Organization of the Thesis

In this research study, some models and strategies of supply chain management were formulated and studied. These models and strategy were solved by using Linear Programming, Fuzzy Linear Programming, Transportation Problem, AHP and TOPSIS, FAHP and FTOPSIS. The thesis is consisting of Five Chapters.

Chapter – I: Introduction

In this chapter, a brief introduction of research topic. supply chain management and development in supply chain management described. A brief literature review of previous research efforts on different types of supply chain management and fuzzy approach methods are discussed. Also, importance of research topic, objectives of the study and research methodology has been described. At the end, an overview of this dissertation work is also presented.

Chapter –II: Optimization of Multi Echelon Supply Chain Management

In this Chapter optimization model is developed by using Linear Programming problem (LPP) for Multi-Echelon and Multimodal supply chain system considering opportunity cost in order to configure the network to minimize total cost. Total cost includes shipping cost from supplier to plant, transportation cost between plants and distribution center, distribution cost between distribution center and customer zones and opportunity cost associated with untimely material availability. At the last an Industrial case study is used to demonstrate the feasibility of applying general Linear Programming Model which results in total cost reduction of supply chain network. This method serves as a straightforward and efficient approach to obtaining optimal solutions for multi echelon supply chain networks. The proposed model is versatile and applicable to both small-scale and large scale industries.

Assumptions of the Model:

- The capacity constraints for suppliers, plants, and distribution centers are fixed.
- The opportunity costs associated with shipping, transportation, and distribution are treated as precise known values.
- The shipping time, transportation time, and distribution time parameters are assumed to be known.
- The demand from customer zones is considered deterministic.

The proposed model considered the concept of opportunity cost into the supply chain design problem. This study Object to

1. Develop a supply chain model that effectively manages and optimizes operations in a deterministic environment.
2. Accurately represent and optimize the utilization of resources, such as shipping, transportation, and distribution capacities, to minimize overall costs.

Objective function

min Z=Supply cost +transportation cost +distribution cost+ opportunity cost

$$\min Z = \left[\sum_i \sum_j \sum_t (C_{ijt} * P_{ijt}) + \sum_i \sum_j \sum_t (C_{jku} * Q_{jku}) + \sum_i \sum_j \sum_t (C_{klv} * R_{klv})\right] + \left[x * \sum_i \sum_j \sum_t P_{ijt} * \alpha_{ijt} + y * \sum_j \sum_k \sum_u Q_{jku} * \beta_{jku} + z * \sum_k \sum_l \sum_v R_{klv} * \gamma_{klv}\right] \quad \dots \dots \quad (1)$$

Subject to constraint:

- **Capacity constraint**

1. Supplier capacity constraint

$\sum_{j,t} P_{ijt} \leq a_i \quad \forall$iI ... ... (2)

2. Plant capacity constraint

$\sum_{i,t} P_{ijt} \leq b_j \quad \forall j \in J$ ... ... (3)

3. Distribution center capacity constraint

$\sum_{j,u} Q_{jku} \leq c_k \forall k \in K$ ... ... (4)

4. Customer zone demand constraint

$\sum_{k,v} R_{klv} \leq d_l \forall l \in L$ ... ... (5)

- **Flow conservation constraints**:

1. Supply conservation: -

$\sum_{j,t} P_{ijt} = a_i \forall i \in I$ ... ... (6)

2. Transportation Conservation constraint:

$\sum_{i,t} P_{ijt} = \sum_{k,u} Q_{jku} \forall j \in J$ ... ... (7)

3. Distribution Conservation constraint:

$\sum_{j,u} Q_{jku} = \sum_{l,v} R_{klv} \forall k \in K$ ... ... (8)

- **Opportunity Constraints:**

1. Opportunity loss constraints for shipping, transportation, and distribution

   $\alpha_{ijt} \geq 0, \beta_{jku} \geq 0, \gamma_{klv} \geq 0 \quad \forall$ i ∈ I, j ∈ J, k ∈ K, l ∈ L, j ∈ J, k ∈ K, t ∈T,

   u ∈ U (9)

2. Opportunity Cost Constraints:

   Opportunity Cost constraints for shipping, transportation and Distribution

   x ≥ 0, y ≥ 0, z ≥ 0 (10)

- **Time constraints**:

Shipping time, transportation time and distribution time constraints

$e_{ijt}, f_{jku}, g_{klv} \geq 0$ ∀ i ∈ I, j ∈ J, k ∈ K, l ∈ L, j ∈ J, k ∈ K, t ∈ T, u ∈ U (11)

- **Non - Negativity constraint**:

All decision variables must be non-negativity

$P_{ijt}, Q_{jku}, R_{klv} \geq 0$, ∀ i ∈ I, j ∈ J, k ∈ K, l ∈ L, j ∈ J, k ∈ K, t ∈ T, u ∈ U (12)

Chapter –III: Application of Fuzzy Transportation and Inventory Model to Optimize Performance of Supply Chain

In this chapter we develop a comprehensive model that optimizes material costs, transportation costs, and inventory holding costs while accounting for uncertainties in facility capacities using fuzzy numbers. We propose a fuzzy mathematical program and compare its solution using the α-cut approach. The model captures uncertainties with trapezoidal fuzzy membership functions for cost coefficients, customer demand, and supplier warehouse capacity. A possibility programming approach transforms the fuzzy model into its deterministic equivalent. The model is tested using LINDO software on a simulated dataset. The model significantly enhances supply chain efficiency by identifying optimal procurement, transportation, and inventory strategies under uncertain conditions. The results of this chapter demonstrate the feasibility and effectiveness of fuzzy mathematical programming and the α-cut solution approach in SCM, offering superior performance over traditional deterministic models by accommodating uncertainties. The model effectively reduces costs and improves operational flexibility, providing a novel and practical solution for real-life supply chain management challenges Introduces a novel approach to SCM by integrating advanced fuzzy logic with traditional optimization techniques.

- **Assumptions of the Model:**

1] The demands for goods at customer location is Non Deterministic.

2] The capacities of supplier, warehouses and customer locations are not fixed

3] No lead times

- **Objective function**

Min Z = transportation cost from Supplier to warehouse + Transportation cost from warehouse to customer + Inventory holding cost at warehouse

$$\text{Min Z} = \left[\sum_i \sum_j (\text{TC}_{ij} * \text{QM}_{ij}) + \sum_j \sum_k (\text{TC}_{jk} * \text{WM}_{jk)} + \sum_j (\text{IHC}_j * \text{e}_j)\right] \quad (1)$$

- **Subject to constraint**

1. Supplier capacity constraint

$$\sum_j QM_{ij} = \text{a}_i \; \forall \; \text{i} \quad (2)$$

2. Constraint for inventory and demand is

$$\sum_i QM_{ij} - e_j \leq b_j \; \forall \; j \quad (3)$$

3. constraint for available space at warehouse is

$$\sum_i QM_{ij} * s_i \leq p_j \; \forall \; k \quad (4)$$

4. Customer zone demand constraint

$$\sum_j WM_{jk} \geq c_k \; \forall \; k \quad (5)$$

- **Non - Negativity constraint**

All decision variables must be non-negativity

$$QM_{ij}, WM_{jk}, e_j \geq 0 \quad \forall \; i, j, \; k \quad (6)$$

- **Fuzzy Transportation Inventory Model**

$$\text{Min Z} = \left[\sum_i \sum_j (\text{TC}_{ij} * \text{QM}_{ij}) + \sum_j \sum_k (\text{TC}_{jk} * \text{WM}_{jk)} + \sum_j (\text{IHC}_j * \text{e}_j)\right]$$

Subject to constraint

$$\Pi \left[\sum_i \sum_j (\widetilde{TC_{ij}} * QM_{ij}) + \sum_j \sum_k \widetilde{TC_{jk}} * WM_{jk)} + \sum_j (\widetilde{IHC_j} * e_j) \leq Z\right] \leq \alpha_1$$

$$\Pi \left(\sum_j WM_{jk} \geq \widetilde{c_k}\right) \leq \alpha_2$$

$$\Pi \left(\sum_i \text{QM}_{ij} - \text{e}_j \geq \widetilde{\text{b}_j}\right) \leq \alpha_3$$

$$\Pi \left(\sum_j QM_{ij} \geq \widetilde{a_i}\right) \leq \alpha_4$$

$$\Pi \left(\sum_i QM_{ij} * s_i \geq \widetilde{p_j}\right) \leq \alpha_5$$

$$\sum_j QM_{ij} = \text{a}_i \; \forall \; \text{i}$$

$$\sum_i QM_{ij} - e_j \leq b_j \; \forall \; j$$

$$\sum_i QM_{ij} * s_i \leq p_j \; \forall \; k$$

$$\sum_j WM_{jk} \geq c_k \; \forall \; k$$

- **α-cut Solution Approach for Fuzzy Transportation and Inventory linear programming model**

In the α-cut solution approach, the fuzzy transportation and inventory parameters are converted into a form that can be handled by traditional linear programming methods by transforming them into crisp values using α-cuts. This transforms the fuzzy model into the Possibility Transportation Inventory Linear Programming (PTILP) model**.**

$$\text{Min } Z = \left[\sum_i \sum_j (TC_{ij} * QM_{ij}) + \sum_j \sum_k (TC_{jk} * WM_{jk)} + \sum_j (IHC_j * e_j)\right]$$

Subject to constraint

$$\left[\sum_i \sum_j (\widetilde{TC_{ij}})^L_{\alpha_1} * QM_{ij} + \sum_j \sum_k (\widetilde{TC_{jk}})^L_{\alpha_1} * WM_{jk)} + \sum_j (\widetilde{IHC_j})^L_{\alpha_1} * e_j \le Z\right]$$

$$\sum_j WM_{jk} \ge (\tilde{c}_k)^L_{\alpha_2}$$

$$\sum_i QM_{ij} - e_j \ge (\tilde{b}_j)^L_{\alpha_3}$$

$$\sum_j QM_{ij} \ge (\tilde{a}_i)^L_{\alpha_4}$$

$$\sum_j QM_{ij} * s_i \ge (\tilde{p}_j)^L_{\alpha_5}$$

$$\sum_j QM_{ij} = a_i \ \forall \ i$$

$$\sum_i QM_{ij} - e_j \le b_j \ \forall \ j$$

$$\sum_i QM_{ij} * s_i \le p_j \ \forall \ k$$

$$\sum_j WM_{jk} \ge c_k \ \forall \ k$$

In the model, α_1, α_2, α_3, α_4 *and* $\alpha_5$represent acceptable risk levels and are also used as alpha cut levels to transform associated fuzzy numbers into crisp values. The notation $(.)^L_{\alpha_k}$ indicates the lower bounds of the α_k level associated with fuzzy variables. For example, $(\widetilde{TC_{ij}})^L_{\alpha_1}$ denotes the lower bounds of the fuzzy number $\widetilde{TC_{ij}}$ at α_1 level, which depends on the membership function of the fuzzy parameters in the model. The fuzzy data may lead to nonlinear constraints related to the model, which can take linear or nonlinear forms. In this model, we utilize trapezoidal fuzzy numbers, as illustrated in Figure 2

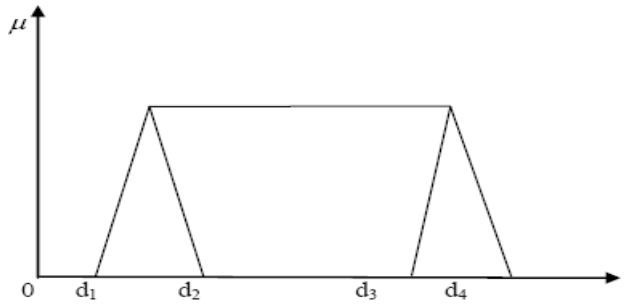

Fig.1.4. Trapezoidal fuzzy number

Figure 1.4 illustrates how a trapezoidal fuzzy number can be transformed into an interval number d = [α* d_2+ (1-α)* d_1,α*d_3+ (1-α)*d_4] using alpha cut techniques. By applying trapezoidal fuzzy numbers, the PTILP model is reduced to a Nonlinear Transportation and Inventory Linear Programming model (NTILP).

$$\text{Min } Z = \left[\sum_i \sum_j (TC_{ij} * QM_{ij}) + \sum_j \sum_k (TC_{jk} * WM_{jk)} + \sum_j (IHC_j * e_j)\right]$$

Subjected to

$$(1-\alpha_1)\sum_i \sum_j (\widetilde{TC_{ij}})_1^L * QM_{ij} + \alpha_1 \sum_i \sum_j (\widetilde{TC_{ij}})_2^L * QM_{ij} + (1-\alpha_1) \sum_j \sum_k \left(\widetilde{TC_{jk}}\right)_1^L * WM_{jk)} +$$

$$\alpha_1 \sum_j \sum_k (\widetilde{TC_{jk}})_2^L * WM_{jk)} + (1-\alpha_1) \sum_j (\widetilde{IHC_j})_1^L * e_j + \alpha_1 \sum_j (\widetilde{IHC_j})_2^L * e_j \leq Z$$

$$\sum_j WM_{jk} \geq (1-\alpha_2)(\widetilde{c_k})_1^L + \alpha_2 (\widetilde{c_k})_2^L$$

$$\sum_j QM_{ij} - e_j \leq (1-\alpha_3)\left(\widetilde{b_j}\right)_1^L + \alpha_3 \left(\widetilde{b_j}\right)_2^L$$

$$\sum_j QM_{ij} = (1-\alpha_4)(\widetilde{a_i})_1^L + \alpha_4 (\widetilde{a_i})_2^L$$

$$\sum_j QM_{ij} * s_i \geq (1-\alpha_5)\left(\widetilde{p_j}\right)_1^L + \alpha_5 \left(\widetilde{p_j}\right)_2^L$$

$$\sum_j QM_{ij} = a_i \; \forall \; i$$

$$\sum_i QM_{ij} - e_j \leq b_j \; \forall \; j$$

$$\sum_i QM_{ij} * s_i \leq p_j \; \forall \; k$$

$$\sum_j WM_{jk} \geq c_k \; \forall \; k$$

Chapter –IV: Comparison of Fuzzy Multi Criteria Decision Making Approaches for Supplier Selection

In this chapter, we discuss the success of any business is depending on an effective supplier selection method. For this purpose, determining the suitable suppliers who are able to provide the buyer with the right quality products, services at the right price and at the right time and also in the right quantities are very important. In supply chain management, supplier selection is a problem for any organization because of its role in reducing cost. It is multi-criteria decision making (MCDM) problem which contains both qualitative and quantitative features and tiny complex because of presenting many criteria. The objective of this chapter is to use Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods in fuzzy environment for supplier selection and compare it. Fuzzy AHP, fuzzy SWARA (Step-wise Weight Assessment Ratio Analysis), fuzzy TOPSIS and fuzzy TOPSIS with fuzzy AHP methods are applied and illustrative example is presented. In the end,

results obtained using different fuzzy MCDM approaches were compared in order to help managers in selecting the best appropriate method for supplier selection problem.

Chapter-V: Optimizing Integrated Supply Chain Costs Through Linear Transportation Model

This chapter presents an integrated supply chain optimization model designed to minimize total transportation costs in supply chain management using a Linear Transportation model. The primary objective is to reduce overall transportation costs within the supply chain, including costs at each stage and inventory costs at warehouses. The model also ensures customer demands are met while considering the capacity constraints of suppliers, manufacturers, warehouses, and customer zones.

The supply chain in this chapter includes four echelons: supplier, manufacturer, warehouse, and customer. Specifically, it comprises six suppliers, two manufacturers, five warehouses, and five customer locations. By integrating these elements into a cohesive optimization model, businesses can make data-driven decisions to enhance supply chain efficiency and lower overall costs.

- **Assumption of the model:**
  1) The demands for goods at customer locations are deterministic.
  2) The capacities of suppliers, manufacturers, warehouses, and customer locations are fixed.
  3) There are no lead times.

Objective function: - Minimize the total supply Chain cost

Minimize $Z=\Sigma\,\Sigma\,\Sigma[TC_{ijpt} * QM_{ijpt}]+\Sigma\,\Sigma\,\Sigma[TC_{jkgt} * QM_{jkgt}]+\Sigma\,\Sigma\,\Sigma[TC_{krgt} * QM_{krgt}] + \Sigma[S_{pit} * IHC_{pit}+ S_{gjt*}IHC_{gjt}+S_{gkt} * IHC_{gkt}]$

- **Subjected to constraint:**

1.Upper Lower bound restriction

$0 \leq QM_{ijpt} \leq QM_{ijpt_upbound}$

$0 \leq QM_{jkgt} \leq QM_{jkgt_upbound}$

$0 \leq QM_{krgt} \leq QM_{krgt_upbound}$

M_{jgt}_Lpbound ≤ M_{jgt} ≤ M_{jgt}_$Ubound$

2.Flow Conservative restrictions

$\Sigma\, QM_{ijpt} = LV_{ipt}$

$S_{pit} + \Sigma QM_{ijp(t-1)} - \Sigma AM_{pg} * M_{jgt} = S_{gj(t+1)}$

$S_{gkt} + \Sigma QM_{jkg(t-1)} - \Sigma QM_{krgt} = S_{gk(t+1)}$

Lastly, the scope for further study is discussed. A comprehensive bibliography is provided at the end of the thesis.

Conclusion: This work makes significant contributions to Supply Chain Management (SCM) by developing classical, fuzzy, and comparative models that optimize multi-tier networks for both large and small-scale companies. facilitates its solution using mathematical programming tools available in the "LINGO" package. Due to the ever-increasing competition where supply chain competes against supply chain, this approach is crucial for achieving cost efficiency and maintaining a competitive edge. These models are highly adaptable, allowing for real-time application and strategic planning. By incorporating fuzzy membership values, the models address variability in costs, capacities, and demands, providing a robust and realistic optimization process. This serves as a powerful optimization tool for supply chain management. A numerical example demonstrates the model's feasibility, offering optimal solutions for minimizing costs under uncertain parameters, thereby better approximating real-life applications compared to traditional models. This model can be extended to account for varying demand and costs, and it can also be applied to fast-moving consumer goods. Future research should focus on enhancing robust optimization and integrating advanced techniques to further improve supply chain operations.

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Dr. Gajanan C. Lomte
Associate Prof. and Research Guide
(CSMSS, Chhatrapati Shahu college of Engineering)

Ms. Sindhu Ramrao Dhavale
Research Scholar

List of Paper Publications, Conferences and Workshops Attended

- **Paper Publications**

1. Dhavale, S. R., & Lomte, G. C. (2022) **Optimization Techniques in Agriculture Sector**. International Journal of Physics and Mathematics, ISSN: 2664-8636, Vol. 4 Issue 1, 2022, Page No.47-49**. (Peer Reviewed)**
2. Dhavale, S. R., & Lomte, G. C. (2023) **Optimization of Multi Echelon Supply Chain Management**. International Journal of Applied Engineering and Technology, ISSN: 2633-4828, Vol. 5 No. S1 Jan-feb (**Scopus Indexing**)
3. Dhavale, S. R., & Lomte, G. C. (2024) Experiments on Supply Chain Management Systems" Indian journal of Technical and Education, ISSN :0971-3034, Volume 47 l No 1.1 Special Issue l January-March (**UGC Care List**)
4. Dhavale, S. R., & Lomte, G. C. (2024). A Comprehensive Fuzzy Model for Cost Optimization in Supply Chain Management. Jr. of Xidian University, ISSN :1001-2400 Volume 18, Issue 8(**Scopus Indexing**)

- **Conferences**

1. Attended and presented paper in titled "**Optimization techniques in Agriculture Sector" in international conference on "**Advances in Computational Sciences "held jointly at Dept. of statistics, Mathematics and Computer Science Yashavantrao Chavan Institute of science, Satara, On 20th & 21th May,2022.
2. Attended and presented paper in titled "**Optimizing Supply Chain Operations under Uncertainty: A Fuzzy Linear Programming Approach"** in National Conference on "Recent Trends In Mathematical Sciences "held jointly at Dept. of statistics and Mathematics, Yashavantrao Chavan Institute of science, Satara On 18th & 19th March,2024.

- **Workshops**

1. Attended International workshop on "Mathematical Modelling and Solution held during 29th February- 4th March,2024 at Woxen University", Hyderabad, Telangana, India.

2. Attended 5 Day National Level Intensive Workshop cum Hands-on Training on "LaTex for writing research Papers & Scientific Documents" from 24.06.2024 to 28.06.2024 by A.C.T ACADEMY, Kerala.